FULL TITLE
ASP Conference Series, Vol. **VOLUME**, **YEAR OF PUBLICATION**
NAMES OF EDITORS

Blazars and the emerging AGN/black hole X-ray binary paradigm

Philip Uttley

X-ray Astrophysics Laboratory, NASA Goddard Spaceflight Center, Greenbelt, MD 20771

Abstract. We briefly review the emerging paradigm which links the radio-quiet and radio-loud classes of AGN to the different accretion states observed in stellar mass black hole X-ray binary systems (BHXRBs), and discuss the relevance of the AGN/BHXRB connection to blazar variability.

1. Introduction

In recent years, a new paradigm has emerged which seeks to link AGN behaviour with that of the stellar mass black hole X-ray binary systems. There are currently two main approaches to this endeavour. One is to compare the temporal variability of AGN and BHXRBs. This approach has already yielded very interesting results, proving that characteristic time-scales scale roughly linearly with black hole mass, and linking the temporal variability of several Seyfert galaxies to that of the BHXRB Cyg X-1 in its high/soft state (e.g. M^{c}Hardy et al. 2004 and these proceedings). The other approach is based on the presence of jets in AGN and BHXRBs, and the relation of the associated radio emission to the X-rays (Merloni, Heinz & di Matteo 2003; Falcke, Körding & Markoff 2004). Also, the relationship of the jet (its presence or absence, and the presence of jet ejections) to the 'state' of BHXRB systems has led to efforts to describe the radio-loud/radio-quiet dichotomy in AGN in terms of analogous states to those seen in BHXRBs (e.g. Meier 2001; Falcke, Körding & Markoff 2004).

2. BHXRB Accretion States

The range of BHXRB behaviour is very diverse, but the following broad picture has emerged, primarily from studies of X-ray transients which move through the full range of states during a single outburst (see McClintock & Remillard 2005; Fender 2005 for reviews).
The *low/hard state* appears to correspond generally to low accretion rates (less than a few per cent of Eddington), with relatively low luminosities and X-ray spectra dominated by a hard (photon index $\Gamma < 2$) power-law continuum, with little or no obvious disk blackbody emission (which can be seen in the X-ray band in BHXRBs, due to their low black hole masses and hence high disk temperatures). Interestingly, all low/hard state BHXRBs show the presence of radio jets, which become stronger relative to the X-ray emission as the source drops to even lower accretion rates, with the power output possibly becoming jet-dominated at some point (Fender 2005).

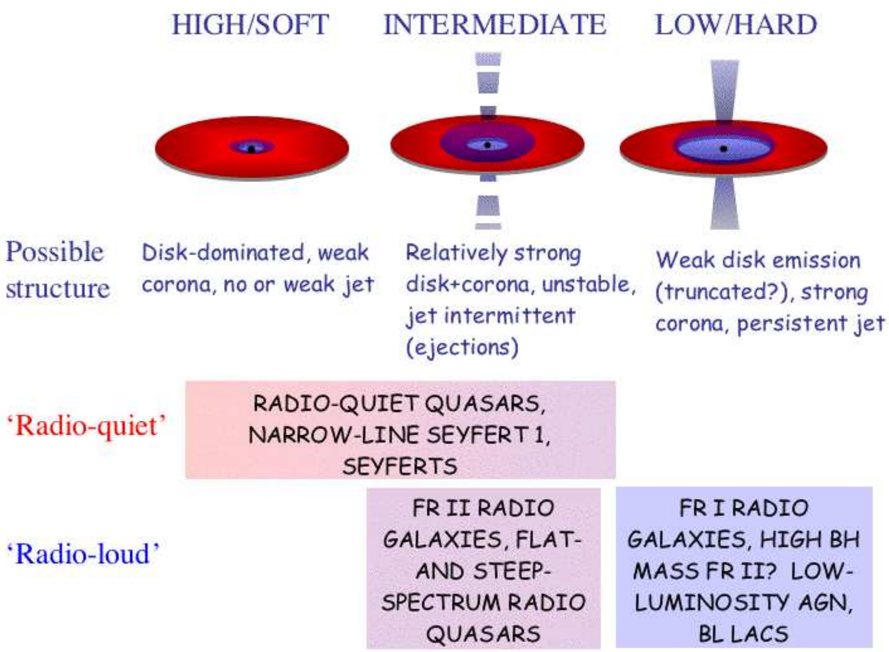

Figure 1. Black hole 'Grand Unification'. The different classes of AGN are grouped in terms of the accretion state they may occupy (see Meier 2001; Falcke, Körding & Markoff 2004 for a similar delineation).

At higher accretion rates (few per cent Eddington or greater), the sources can transition to a *high/soft state* where the emission is dominated by blackbody emission from the accretion disk, with only a very weak, steep ($\Gamma > 2$) power-law component present. The high/soft state is very interesting from the point of view of understanding BHXRB jets, because they become much weaker or may even disappear completely during this state, with the radio emission becoming undetectable (> 30 times fainter than the low/hard state)
Bridging the power-law dominated and disk dominated states described above is the *intermediate state* or *very high state*. The different names reflect the fact that the transition between a power-law-dominated and disk-dominated state can in fact be observed at either relatively low (few per cent Eddington) or rather high (tens of per cent Eddington) accretion rates, but the behavior is similar in either case and both types of transition state are now commonly thought of as being the same thing, which we will refer to as the intermediate state. As the name suggests, the intermediate state shows a spectrum intermediate between the low/hard and high/soft states, with relatively strong disk and strong steep ($\Gamma > 2$) power-law contributions. The fraction of luminosity contributed by each component varies, so the state is in some sense loosely defined and can be quite unstable, flipping between more power-law dominated and disk dominated spectra on relatively short time-scales. The jet behaviour is also very interesting, with powerful relativistic ejections occuring as the disk component gets stronger (possibly connected to the quenching or disappearance of the jet in the high/soft state) although a persistent jet can exist in the more power-law dominated types of intermediate state.

3. Black hole Grand Unification

The existence of the same states in AGN would be highly interesting, not only from a spectral and variability point of view, but also in terms of understanding the radio-loud/radio-quiet dichotomy, because it is clear from BHXRB studies that states with and without jets can occur in the same source. Therefore, it is possible that the presence of powerful jets in AGN may be related to the accretion state, and not necessarily to the black hole spin or AGN environment. The types of state seen in BHXRBs seem to be related to the interplay of the disk and power-law emission (perhaps the latter from a corona), and the presence and/or strength of the jet seems to be correlated with the presence of the power-law component. With this simple picture, we can construct a picture of 'Black Hole Grand Unification', shown in Fig. 1, where the distinction between radio-loud and radio-quiet AGN is governed by whether the source occupies the strong-jet, strong-corona states (low/hard and parts of the unstable intermediate state) or the weak-jet, disk-dominated states (high/soft and disk-dominated parts of the intermediate state).

Note that we have classified low-luminosity AGN as low/hard state sources, as previously suggested by (Ho 2005) in line with their low accretion rate and their unusual spectral energy distributions (SEDs), which do not show 'big blue bumps' (suggesting that the disk is truncated), and relatively strong radio emission (suggesting relatively strong jets).

The dividing line between the distinctive high/soft and low/hard states and the intermediate state is murky. In BHXRBs these states can be distinguished from the intermediate state by their relative stability and X-ray colours (since the relative contributions of disk and power-law emission can be assessed in this way), but in AGN we cannot cleanly see most of the disk emission, which occurs in the FUV/EUV, so it is hard to judge whether a source SED is disk or power-law dominated. Changes from power-law to disk dominated and back again can take hours to weeks in BHXRBs, corresponding to thousands to millions of years for a 10^8 $M_\odot$ black hole, so for any given AGN we can only realistically observe a 'snapshot' of it in a single state. These limitations would make it difficult to distinguish between high/soft and intermediate states with strong disk emission, hence we might expect Seyferts and radio-quiet quasars to occupy either state. The intermediate and high/soft states are not tightly tied to accretion rate, but are observed above a few per cent Eddington, whereas only the low/hard state is seen at lower accretion rates (Maccarone 2003). Thus it may be possible to distinguish low/hard and power-law dominated intermediate states in the radio-loud sources, in terms of the luminosity and power of the source. In general, one might expect FR II radio galaxies to correspond to the more powerful, higher accretion rate intermediate states, while FR I sources correspond to the low/hard state, but more massive black holes may possess sufficiently powerful jets that they correspond to FR II sources in the low/hard state also.

4. Implications for Blazars

Following the standard paradigm for unifying blazars with non-beamed radio-loud AGN, we can roughly map the BL Lac sources on to the low/hard state,

and more powerful flat spectrum and steep spectrum radio quasars on to the intermediate state. The lack of significant optical permitted line emission, which distinguishes BL Lac objects and maps them on to FR I radio galaxies in the standard unification paradigm may be related to the lack of any significant disk emission which can drive the optical line emission (see Ho 2005).
Interestingly, the timing behaviour of the different BHXRB states may shed light on variability behaviour of blazars, and offer a tantalising glimpse of what *GLAST* might reveal in sufficiently long blazar light curves. In BHXRBs, strong quasi-periodic oscillations (QPOs), typically at around 1-10 Hz, are often observed in the intermediate state, especially the power-law dominated part, i.e. when a strong jet is present. If the variations are produced in an accretion flow which is coupled to the jet, similar behaviour might be seen in the blazars which occupy this state, but on time-scales of years (assuming linear scaling of QPO time-scales with black hole mass). In fact, periodic (or possibly quasi-periodic) continuum variations on time-scales of years have been claimed in a number of blazars, most notably OJ 287 (e.g. Valtaoja et al. 2000). These candidate periodicities [1] are often interpreted as being due to precession of the jet caused by a binary black hole system, but it is interesting that they occur on similar relative time-scales to the strong QPOs observed in the possibly analogous BHXRBs in the intermediate state, where the QPOs are probably intrinsic to the accretion flow and are not attributed to binary motion. When *GLAST* is launched, it will provide high quality gamma-ray light curves for many blazars, which, if the mission is flown for sufficient duration, may be sufficient to detect periodicities in the lower-mass blazars and test the remarkable AGN/BHXRB connection still further.

References

Falcke, H., Körding, E. & Markoff, S. 2004, A&A, 414, 895

Fender, R. 2005, to appear in W. H. G. Lewin, M. van der Klis eds., Compact Stellar X-ray Sources, Cambridge University Press, Cambridge (astro-ph/0303339)

Ho, L. C. 2005, to appear in 'From X-ray Binaries to Quasars: Black Hole Accretion on All Mass Scales', ed. T. J. Maccarone, R. P. Fender, and L. C. Ho, Dordrecht: Kluwer (astro-ph/0504643)

Maccarone, T. 2003, A&A, 409, 697

McClintock, J. E. & Remillard, R. A. 2005, to appear in W. H. G. Lewin, M. van der Klis eds., Compact Stellar X-ray Sources, Cambridge University Press, Cambridge (astro-ph/0306213)

McHardy, I. M., Papadakis, I. E., Uttley, P., Page, M. J. & Mason, K. O., 2004, MNRAS, 348, 783

Meier, D. 2001, ApJ, 548, L9

Merloni, A., Heinz, S. & di Matteo, T. 2003, MNRAS, 345, 1057

Valtaoja, E., et al. 2001, ApJ, 531, 744

Vaughan, S., & Uttley, P., 2005, proceedings of 35th COSPAR (astro-ph/0506456)

[1] The sampling and number of cycles observed may not yet be sufficient to show that the variations are strictly or quasi-periodic and not simply due to red noise (e.g. see discussion in Vaughan & Uttley 2005).